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An Investigation of Wastewater Management Options for the Community of Fatima, Costa Rica

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An Investigation of Wastewater Management Options for the Community of Fátima, Costa Rica

An Interactive Qualifying Project Report



Submitted to the Faculty of
WORCESTER POLYTECHNIC INSTITUTE
In partial fulfillment of the requirements for the
Degree of Bachelor of Science

Submitted on:
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Sponsoring Agency: Integral Development Association of Fátima

Submitted to:

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Abstract

In the community of Fátima in Desamparados, Costa Rica, the residents currently discard untreated wastewater in the Quebrada Padre. This has caused the water quality in the river to degrade. Our first goal was to assess the residents' perceptions of the river conditions and their wastewater disposal methods through interviews and a site assessment. Results indicated that residents had mixed perceptions of the river and may not know how their wastewater is disposed. We then evaluated wastewater management options based on maintenance, cost, constructability, durability, safety, and effectiveness. We recommend that the existing household infrastructure be connected to the existing municipal sewer to improve the quality of the Quebrada Padre.

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Finally, we would like to thank the members of the faculty at Worcester Polytechnic Institute for their hard work in developing this program and for making this experience possible.

Executive Summary

In the community of Fátima, the residents currently discard untreated wastewater in the Quebrada Padre. The families are not able to connect to the municipal sewer system because their houses are located at a lower elevation than the municipal piping network. They also cannot install a septic system because their land is highly impermeable. Discarding untreated wastewater into the river degrades the water quality and increases the risk of pathogen transmission to humans. Implementing a different wastewater treatment and/or disposal system would decrease this risk and improve the water quality in the river.

Our first goal was to determine the current infrastructure of the wastewater disposal system in Fátima and to assess the perceptions of the residents regarding their current system. Information was gathered through a site assessment and interviews. We found that the current system transported sewage through pipes leading from each household to the river without any treatment. However, there seems to be a disconnect between how the sewage is disposed and how residents believe it is disposed, as some believed their wastewater is collected by the municipal sewer system. There was also a conflict between the level of contamination of the river and the level of contamination that the residents perceived. Through our visual assessment, we observed that the section of the river adjacent to the homes was contaminated. However, less than two-thirds of the residents that border the river reported that it was contaminated. Lastly, there are varying attitudes about the current state of the river, as some of the residents are not bothered by the river, while others are bothered. Based on these findings, we determined that a different wastewater treatment and/or disposal system should be implemented.

Our second goal was to evaluate wastewater management options for limiting the contamination in the Quebrada Padre and to investigate potential financing options for implementation of the chosen system. We researched centralized and decentralized wastewater treatment options, including both natural and engineered systems, as well as connection to the municipal sewer. We evaluated each system based on criteria including maintenance, cost, constructability, durability, safety, and efficiency. The most viable solution was determined to be connecting the existing pipes to the municipal sewer system. In comparison to other options, the proposed option is low in cost, maintenance, and construction.

In order to implement this system, potential options for financing the capital costs were determined. These include contributions from the residents, fundraising efforts, and financial aid from external sources. We recommend continued research on these options. Additionally, we recommend a study to determine the most effective way to adjust environmental attitudes and behaviors of the residents. These strategies may include development of educational outreach programs to increase awareness about environmentalism and to help sustain environmental practices within the community. We believe that our findings and recommendations will ultimately improve the quality of the Quebrada Padre.

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Chapter 1 – Introduction

Costa Rica has recently displayed many efforts to be environmentally friendly, as evidence by their goal to reach carbon neutrality, their efforts to utilize renewable energy, and their policies for the conservation of energy and forestry (Frankie, Mata, & Vinson, 2004). While progress has been made in these areas, Costa Rica still has many wastewater pollution problems to address (United States. Dept. of State, 2011; Frankie et al., 2004). Wastewater, or sewage, is a combination of black and grey water. Black water consists of used water with fecal matter and urine, while grey water is used water from bathing, household cleaning, dish washing, and clothing laundering. Overall, less than 3 percent of the wastewater generated in Costa Rica is treated and the remaining 97 percent is discarded into local rivers (Williams, 2011).

Population growth is one of the factors contributing to wastewater pollution in Costa Rica. Before the 1960s, the population of the country had been consistently small. However, between 1960 and 1980, there was a substantial growth (Evans, 1999). This growth occurred more rapidly than the extension of wastewater management. For example, sewage services in the cities of Guanacaste initially incorporated 70 percent of the population in urban regions (Frankie et al., 2004). However, after a growth in population, these services were not extended to the new communities and consequently only 33 percent of the urban locations in Guanacaste have adequate sewage collection and treatment (Frankie et al., 2004). Many of the communities without these resources dispose of their sewage in local bodies of water.

Discarding wastewater into local bodies of water can negatively impact human health and degrade the natural environment. Pollutants in wastewater include pathogens, which can cause infections in humans ranging from diarrhea to gastroenteritis and hepatitis (Baer, 2011). Wastewater also contains organic matter, specifically oxygen demanding substances, which are aerobically biodegraded in the receiving water body. When waste with high levels of organic matter is introduced into a river or stream, oxygen is depleted which can compromise aquatic life (Penn et al., 2002).

Pollutants in wastewater can be reduced through treatment, which can be done in either a centralized or decentralized manner. Centralized treatment collects the wastewater created by a community or city and transports it to a common facility for treatment. Decentralized treatment collects sewage from one to a few households for treatment on-site. Proper wastewater treatment

is particularly important in urban areas where there are higher concentrations of people. Communities without the appropriate facilities are forced to dispose of wastewater through other means, such as discarding it directly into local rivers.

In Fátima, a neighborhood in the district of Desamparados, San José, the residents who border the Quebrada Padre have insufficient wastewater management. Specifically, these residents discard wastewater into the local river. In order to eliminate this discharge, the local development association has focused their recent work on implementing a wastewater management system. Since 1974, La Asociación de Desarrollo Integral de Fátima, or the Integral Development Association of Fátima (the Association) has had the goal of improving the quality of life for the families in Fátima through private and government alliances. They work to improve the infrastructure by constructing and repairing facilities used for education, medical purposes, and social gatherings (The Association, personal communication, Oct. 29, 2011).

Our project aligns with the goals of the Association by aiming to improve infrastructure of the current wastewater disposal system in order to enhance the quality of life for the residents. We investigated this project through the completion of two studies. The goal of Study 1 was to identify the current disposal system of Fátima and to assess the attitudes of the residents towards their current system and the state of the Quebrada Padre. Study 2 aimed to determine a wastewater management system that most accurately meets the needs of Fátima. Implementing a new sewage management option would reduce the presence of waste in the Quebrada Padre, thus improving the water quality and reducing human exposure to contaminants that can cause diseases. If the proposed system is implemented, it can be replicated for similar communities in Costa Rica.

Chapter 2 – Study 1: Research on Perceptions and Infrastructure

This chapter details the investigation of the current situation in Fátima regarding wastewater management and residents' perceptions regarding this system. The first objective was to determine the existing infrastructure to identify and understand specific issues with the wastewater management system. The second objective was to assess the perceptions of the residents regarding their wastewater and the Quebrada Padre. We gathered data on the current situation through site assessments and interviews. The results were analyzed and used to design the second study and recommend areas for future research.

2.1 Background: Strategies for Initiating Behavioral Change

Identifying current attitudes and behaviors of the residents of Fátima in regards to the environment is useful because these do not always align. As illustrated by the theory of cognitive dissonance, attitudes and behaviors in individuals do not always correlate (Festinger, 1962). Cognitive dissonance is a feeling of discomfort that presents itself when attitudes and behaviors do not connect. This feeling leads to one of three options: 1) the individual will change their attitude, 2) the individual will change their behavior, or 3) the individual will slightly modify their attitude to justify their behavior (Festinger, 1962). The driving force behind cognitive dissonance is the need for individuals to feel consistent. Consistency is a large factor in affecting the way that people behave (Cialdini, 2001; DeYoung, 1993; Shell & Moussa, 2008). Because of the need to remain consistent in a given situation, there is no guarantee that an attitude will always lead to a behavior, or vice versa.

Besides the desire to be consistent, a variety of factors influence both attitudes and behaviors individually. One major factor is the influence of others' attitudes. In particular, individuals often rely on the consensus of a group when deciding how to act, which is known as social influence (Nolan, 2008). When the number of people performing an action increases and individuals become aware of this number, the likelihood that more people will also adopt this behavior also increases (Cialdini, 2003). For instance, one study showed that making people aware that others were acting environmentally friendly was the most effective method for

creating pro-environmental behavior change, despite the fact that the participants did not perceive it as the factor that had the most influence in their behavior change (Nolan et al., 2008).

In addition to the influence of the attitudes of others, people are more likely to listen to those that they perceive as authority figures, such as local organizations and the government (Cialdini, 2001). Gaining the support of institutions is very influential because it employs a combination social influence and authority to encourage a behavior change (Quimby & Angelique, 2011). However, the effects of social influence are not always positive, as people can also be influenced by the commonness of negative actions. Caution should be taken when designing promotional messages communicating positive things, such as the need to clean a city. If it is depicted that many people are contributing to a negative action, such as pollution, it may prolong it rather than counteract it (Cialdini, 2003).

Additionally, there are certain barriers that prevent attitudinal and behavioral change. Some of the main barriers to pro-environmental behavior change include lack of time and lack of money (Shell & Moussa, 2008; Quimby & Angelique, 2011). These barriers are presented when alternative options require an increased amount of time and money. This is especially true for communities with a lower socioeconomic statute (SES; Quimby & Angelique, 2011). One reason this may be particularly true for communities with a lower SES is that individuals, according to Maslow (1943) are less concerned with a higher level of needs until the more basic needs are satisfied (see Figure 1 for the pyramid often used to represent the hierarchy of needs). More specifically, Maslow asserts that people will be more concerned with assuring their financial, physical, mental, and health related stability before achieving goals that are more abstract in nature, such as addressing global environmental concerns. In communities like Fátima, where money is one of the main barriers towards changing their wastewater management practices, the residents may not have their financial needs met (The Association, personal communication, Sept. 14, 2011).

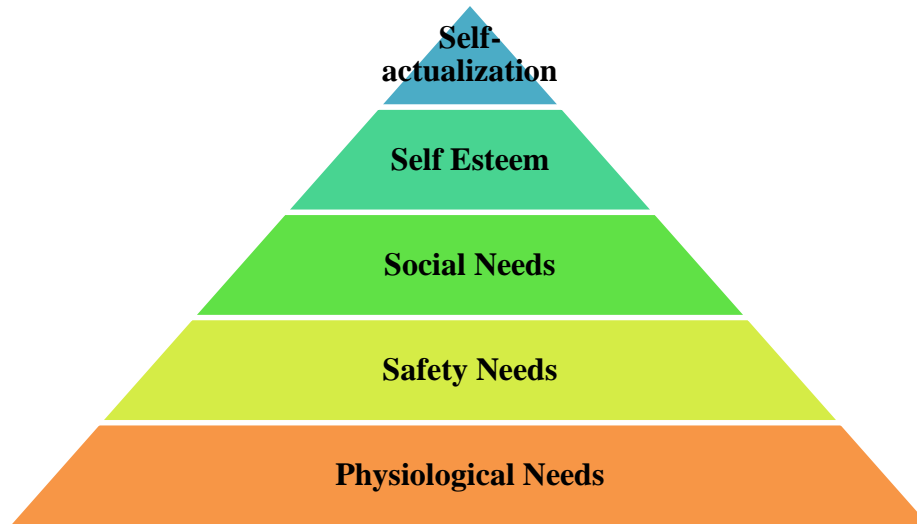


Figure 1. Theory of human motivation pyramid (Created based on Maslow, 1943).

Since so many factors influence attitudes and behaviors, it is important to assess them in order to begin the development of ways to improve the environment for the residents bordering the Quebrada Padre. Determining the current attitudes and behaviors in Fátima is important in order to better understand the current perceptions of the resident in relation to their current wastewater management practices. This could help in identifying the specific needs of the community in regards to pro-environmental attitudes and behaviors, which provides a basis on which future research can expand. The following methods were designed to accomplish these goals.

2.2 Methods of Study 1

The goals of this study were to determine the current wastewater infrastructure in Fátima and to assess the perceptions of the residents towards the Quebrada Padre. First, we conducted a site assessment to determine the infrastructure and physical layout of the neighborhood. Second we conducted interviews with local organizations including the Association and Instituto Costarricense de Acueductos y Alcantarillados (AyA). AyA is the government organization in Costa Rica responsible for drinking water and wastewater management. We then conducted interview with representatives of the households bordering the Quebrada Padre that were willing to participate and documented their responses about the current wastewater disposal system.

2.2.1 Current Infrastructure

In order to assess the current wastewater infrastructure, we conducted a site assessment and interviews with representatives of the Association and AyA. First, we toured the community to understand the current layout of the neighborhood. We recorded the number of houses bordering the Quebrada Padre in order to gain a better understanding of number of stakeholders. In addition, we assessed the water quality in the Quebrada Padre. To do this, we visually observed the water quality in the river at three different locations: (1) approximately 300 meters upstream from the first home in Fátima, (2) adjacent to the southernmost home along the river, and (3) downstream of the northernmost home. While conducting our observations, we assessed: (1) whether there was trash, or solid waste, in or around the river, (2) whether there were pipes discharging human waste generated outside of Fátima, (3) the clarity of the river, and (4) any odors. The homes that border the Quebrada all have similar infrastructure, therefore to understand the wastewater infrastructure, we observed the plumbing of one of the homes.

In addition to the site assessment, we interviewed two active members of the Association. From this interview, we assessed the mission and work of the Association, information on current wastewater systems in Fátima, and attitudes of the residents about their current wastewater disposal system. We also inquired about land availability in the neighborhood and the town budget available for wastewater management.

2.2.2 Community Attitudes and Awareness Study

Participants. We interviewed 10 adult residents (2 males; 8 females) in Fátima. All participants were over the age of 18. These residents represented 10 out of the 30 families. The residents were randomly sampled by door-to-door solicitation and participated voluntarily. There was no monetary compensation for participating in the interview.

Procedure. We assessed the perceptions of the residents on their current wastewater disposal system and on the condition of the Quebrada Padre through interviews. In particular, the questions assessed how the residents believed their wastewater was disposed, their perceptions towards the contamination of the river, and their attitudes towards the contamination of the river (see Appendix A for all interview questions). To analyze the interview responses, we coded the

qualitative responses. To do so, each group member ranked the responses of all participating residents on a 4-point scale, where 0 meant the resident was not bothered by the river at all and 3 meant that the river bothered the resident greatly. The mode of all of the responses was taken for each participant and percentages were calculated based of the mode. We conducted an inter-rater reliability analysis to ensure the coders were consistent. The results of this analysis showed that the coders had a high inter-rater reliability, Cronbach $\alpha = 0.89$.

2.3 Results of Study 1

Current Wastewater Disposal Infrastructure. The site assessment in Fátima included three parts: (1) visual observations of the layout of the community and land constraints, (2) visual observations of the Quebrada Padre, and (3) observation of the current wastewater disposal system of one of the 30 households that border the Quebrada Padre. Figure 2 shows the neighborhood of Fátima. The houses bordering the Quebrada Padre are indicated with the red box on the map. The river is shown in blue, and flows from south to north.



Figure 2. Fátima and the Quebrada Padre: Thirty Households in Fátima (red box) along the Quebrada Padre (blue line), with the field used for recreation (green box). (Source: Google, 2011, with modifications)

First, the community layout and land constraints were observed. The houses were very close to each other and there was insufficient space for centralized treatment near the households. However, a field located about 100 meters northwest of these households, as approximated by the scale in Figure 2, was large enough to house a centralized treatment facility (The Association, personal communication, Nov. 30, 2011). This field, currently used for recreation purposes, is shown by the green box in the map.

Next, the water quality in the Quebrada Padre was assessed through visual observations. The region that was inspected began approximately 300 meters upstream of the community, as approximated by the scale of the map, and extended to the westernmost households along the river. Prior to the assessment, the Association stated that the water was clear and odorless in the upstream areas. They also noted that there were no major sources of solid or human waste deposited into the Quebrada Padre in this upstream area. These indications were confirmed through the visual assessment of the Quebrada Padre. The upstream reach of the river had clear water and a visible river bed. It also did not have any observable foul odors, trash, or pipes

emptying waste from outside of Fátima. The downstream section of the river, which is adjacent to the households, also did not have any observable trash or pipes emptying waste from outside of Fátima. However, the water in this location had a grayish-green color and an unpleasant odor. A visual comparison of water quality is displayed in Figure 3. Therefore, the primary source of pollution in this section of the river appears to be the disposal of sewage from the households in Fátima bordering the river.



Figure 3. Conditions of the Quebrada Padre: Water upstream of the houses (left), and downstream of the houses (right). (Photos by Stephany Vasquez, 2011)

The Association and AyA stated that each home has two pipes made of PVC that run through the backyard and empty into the river. Specifically, one pipe drains black water from toilets and another pipe drains grey water from sinks and showers. Site observations confirmed the presence of these piping systems. Pipes leading from the household to the river are shown in Figure 4.



Figure 4. Current wastewater infrastructure: Pipe connecting wastewater from a house to the Quebrada Padre (left). Pipe outlet directly above the Quebrada Padre (right). (Photos by Stephany Vasquez, 2011)

After the completion of the visual assessments, interviews were administered to the residents living along the river. One of the questions asked residents what they use as a wastewater disposal system. The responses were recorded as one of three options: unknown, connected to public sewer, or piping. The answers are depicted in Figure 5: 30% indicated that they did not know their current system, 40% indicated they had piping that transported their wastewater to the Quebrada Padre, and 30% of participants indicated that they were connected to the sewer. A chi-squared analysis was performed to determine if there is a significant difference between the responses. The analysis showed that there was no difference in the number of residents who believed they were connected to the sewer (30%) compared to the number of participants that believe they used piping to the river (40%), $\chi^2 (1, N = 10) = 1.43, p > 0.20$. From this, we concluded that there is not one distinct consensus of how the wastewater is discarded.

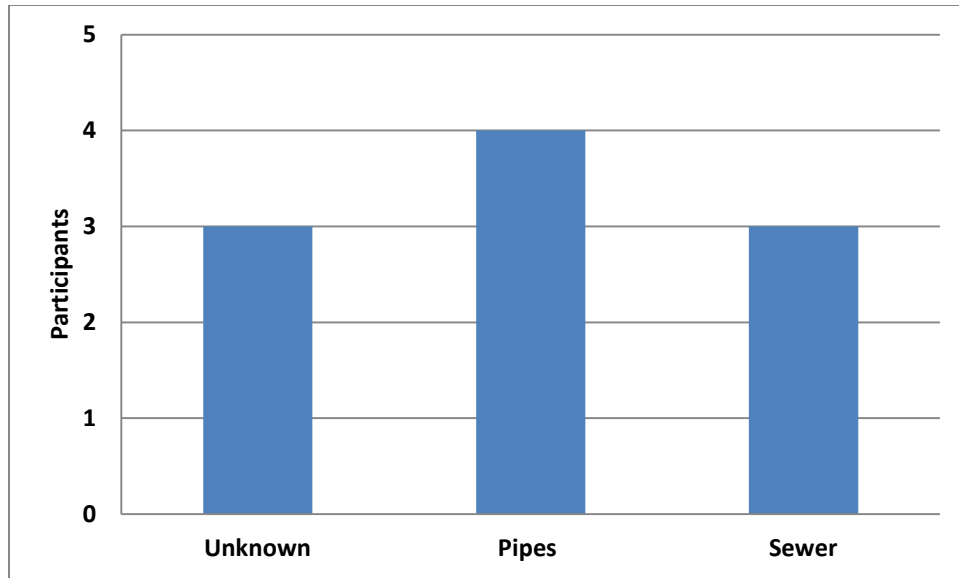


Figure 5. Responses regarding the current wastewater disposal infrastructure.

The community interview results conflicted with information gathered from interviews with the Association and AyA. Both organizations confirmed that all of the households were connected to pipes that carried their wastewater to the Quebrada Padre. Another chi-squared analysis compared the percentage of residents who reported using pipes (40%) versus the percentage of those unknown and those who stated they were connected to sewer (60% [30% + 30%]). This analysis shows that the majority of the residents either are unsure where their sewage goes or believe they are connected to a sewer, $\chi^2 (1, N = 10) = 4, p < 0.05$. Overall, this indicates that a majority of the residents may not know where their waste is going.

Attitudes of Residents. Residents also indicated their perception of the level of contamination of the Quebrada Padre. The residents specified whether the river is slightly, moderately, or very contaminated. The results showed that 0% said that the river was slightly contaminated, 0% said it was moderately contaminated, 60% said it was very contaminated, and 40% said that they did not know the level of contamination. A chi-squared analysis compared the percentage of residents believing the river was very contaminated (60%) versus the percentage that did not know (40%), $\chi^2 (1, N = 10) = 4, p < 0.05$. This indicated that significantly more residents in the community believed that the Quebrada Padre was contaminated than those who

did not know. However, this also indicated that more than one-third of the residents are unaware of the current level of contamination of the river.

We also aimed to gain information about how the residents felt about the current state of the Quebrada Padre. Participants specified if they were not bothered, slightly bothered, or bothered by the current state of the river. Since the responses were open-ended we used a scale to code them on a scale from 0 to 3 responses. The code 0 meant they did not indicate an attitude towards the river, 1 meant they were not bothered, 2 meant they were slightly bothered and 3 meant they were bothered. Each group member coded each of the responses. An inter-rater reliability analysis was conducted to determine the reliability of the coding system which proved the numbers were reliable. The results, depicted in Figure 6, showed that 10% did not indicate an attitude towards the river, 30% are not bothered by the contamination of the Quebrada Padre, 20% are slightly bothered, and 40% are bothered. A chi-squared analysis was performed to measure the percentage of residents not bothered and slightly bothered (30% + 20%) by the river versus the percentage that was bothered (50% vs. 40%), $\chi^2 (1, N = 10) = 1.11, p > 0.25$. This showed that there was not a significant difference between those residents bothered and those not greatly bothered by the current state of the Quebrada Padre.

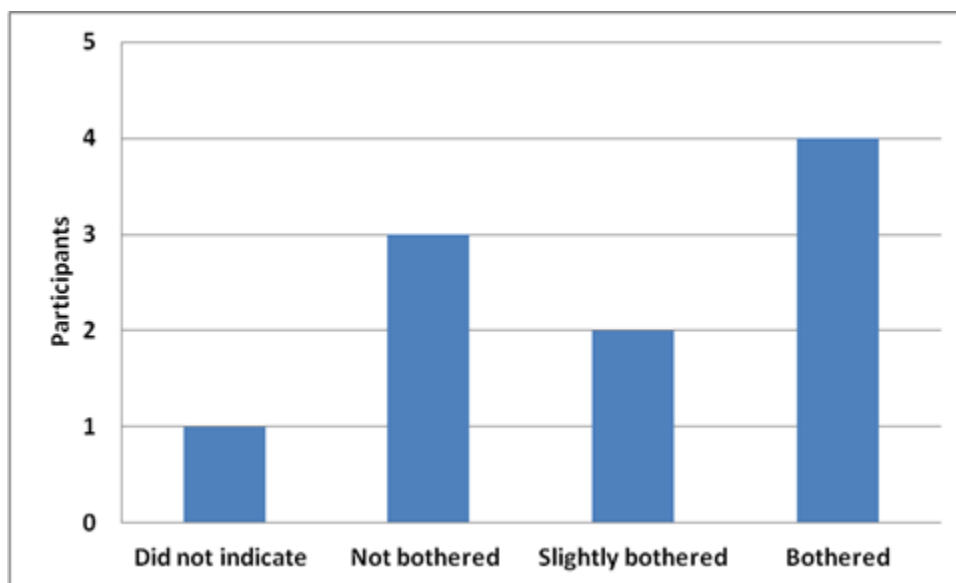


Figure 6. Attitudes of residents towards pollution of the Quebrada Padre.

In addition to the results of the interviews, we obtained information from the Association and AyA on resident attitudes. A representative of AyA indicated that treatment systems implemented in nearby communities in the past were unsuccessful due to lack of interest among residents in maintaining the facilities (AyA, personal communication, Nov. 14, 2011). In Fátima, a representative of the Association stated that there was a lack of interest from the residents in past meetings about wastewater management (The Association, personal communication, Nov. 30, 2011). This information should be considered before implementing any wastewater management strategies in Fátima.

2.4 Discussion of Study 1

In Study 1, we examined the current wastewater infrastructure for the houses that border the Quebrada Padre and assessed residents' attitudes towards the river. Information from site observations and interviews showed that the 30 houses that border the Quebrada Padre discard their wastewater through PVC pipes into the river. However, less than half of the residents reported that they discarded their wastewater into the river. Thus, there seems to be a disconnect between how the sewage is disposed and how residents believe it is disposed. We recommend future research to investigate why this disconnect exists in order to develop methods to increase community awareness on the issues surrounding wastewater disposal in the river.

The section of the river adjacent to the houses was visually more contaminated than the upstream section of river, likely due to untreated wastewater discharges from the homes. However, slightly less than two-thirds of the residents reported that the river was contaminated. Additionally, there is not one predominant attitude about the river, as some residents reported being bothered by the level of contamination, whereas others reported not being bothered. There again seems to be a disconnect between the level of contamination in the river and residents' perceptions of the water quality. We recommend future research to investigate why this disconnect exists to help increase community awareness on the issues of the river contamination. In conclusion, the results of this study suggest that a different wastewater treatment and/or disposal system should be implemented; therefore, we examined alternatives in Study 2.

Chapter 3 – Study 2: Wastewater Management Proposal

This chapter outlines the research, analysis, and recommendation of wastewater management systems for use in the community of Fátima. In the previous chapter, we found that the water quality in the Quebrada Padre has been degraded due to the current wastewater management practices. The goal of this study was to determine a wastewater treatment and/or disposal system that reduces pollution in the Quebrada Padre. First, we researched options for wastewater treatment and/or disposal. Then, we selected a system based on the needs of Fátima. After selecting a system, financing options for implementation were investigated.

3.1 Background: Wastewater Management Options

The management of wastewater can be performed through three different approaches. Wastewater can be (1) treated in a centralized setting, (2) treated in a decentralized setting, or (3) redirected to an outside site. In centralized treatment, wastewater is transported from a community or city to a common facility for treatment. In decentralized treatment, wastewater is collected from one to a few households and is treated on-site. With redirection, wastewater generated by a given community is transported to a certain location for treatment and handling by an outside group. Redirection differs from centralized treatment in this context because this process does not include a treatment within the community but is a disposal system to eliminate pollution in local surface waters. Within these approaches are various alternative treatments, as shown in Table 1. The advantages and disadvantages of each system are also given.

Table 1. Wastewater management systems organized by type.

Type	Alternative Treatments	Type of Wastewater	Process	Pros	Cons
Centralized	Aerobic	Both	Engineered aerobic microbial degradation	Uses limited land, some methods require little maintenance	High levels of sludge produced, can have high costs
	Anaerobic	Both	Engineered anaerobic microbial degradation	Produces biogas, causing low energy costs	High installation costs, cannot remove all excess nutrients
	Pond/Lagoon	Both	Aerobic and anaerobic in a constructed or natural setting	Inexpensive, works well in hot climates	Land constraints
Decentralized	Composting Toilets	Black	Aerobic microbial degradation of solid waste	Can be built to lower costs, low levels of sludge	Already have toilets in homes
	Septic	Both	Solid settlement and anaerobic microbial degradation	Required by Costa Rican law, works with current infrastructure	Expensive installation and maintenance
Redirection	Connection to Sewer System	Both	Redirection to connect with the rest of the community	Cost effective, builds off of current infrastructure	Wastewater is not treated prior to leaving the community

While Table 1 highlights the treatment and/or disposal systems that were investigated, there are other aspects of wastewater treatment and/or disposal. In general, wastewater can be treated three different ways: (1) separate black water treatment, (2) separate grey water treatment, and (3) combined black and grey water treatment. Unlike grey water, black water contains a high concentration of solids, organic matter, and pathogens and therefore requires a more comprehensive treatment process (Black Water Recycling Systems, 2010). Treating black water is more important than treating grey water in order to maintain human and environmental health; therefore, separate grey water treatment will not be discussed further. The focus of this project was on treating black water and the combination of black and grey water.

All treatment options for wastewater or black water involve the production of sludge. Sludge is a byproduct of the biological digestion of organic matter in sewage. It is also known as biofilm or biomass. There are multiple options for the reuse or disposal of sludge, and the option selected dictates what treatment the sludge must undergo. Sludge can be reused as fertilizer if it is anaerobically digested. If liquids in sewage are not removed prior to digestion, then the final product is liquid-form fertilizer. If the liquids are removed prior to digestion, then the final product is compost. If sludge is not reused, it can be incinerated. Overall, sludge treatment is outside the scope of this project for a more detailed analysis, but it is important to consider the

role of sludge in the selection of a wastewater management system. The following sections discuss in more detail each of the alternative treatments listed in Table 1.

3.1.1 Engineered Aerobic Treatment Systems

Engineered aerobic treatment systems are centralized treatments that use aerobic digestion to reduce the concentration of organic matter and solids in wastewater. Aerobic digestion is a biological process where bacteria use oxygen to degrade organic matter. Carbon dioxide is released as a byproduct of the process. The bacterial decomposition can occur on a surface (fixed film) or in a mixed liquid (suspended growth). In both cases, bacteria transform dissolved organic matter into solid biomass that can be separated from the water. The separation generally occurs in a separate tank called the secondary clarifier (Davis & Masten, 2009). Membranes, specifically referred to as membrane bioreactors (MBRs), can be used as an alternative to a secondary clarifier to separate solids and liquids (Mara & Horan, 2003). MBRs have high costs and require frequent cleaning and maintenance.

Aerobic digestion is a secondary treatment process. It is generally preceded by pre-treatment and primary treatment, and followed by tertiary treatment. Pre and primary treatments remove large solids and a portion of the organics in the wastewater. Tertiary treatments are used to target particular contaminants if the biodegradation does not eliminate all necessary pollutants. Tertiary treatment is beyond the necessary scope of this project, and will not be further discussed.

3.1.1.1 Pre-Treatment and Primary Treatment

Pre-treatment and primary treatment are used as the first stage of the engineered aerobic treatment of wastewater. The objectives of these initial processes are to reduce the amount of solids, improve the efficiency of biological treatments, and limit damages to pumps or mechanical equipment. First, wastewater is passed through bar racks and screens to remove bulk material such as wood, stone and/or, plastic (Forster, 2003). Second, wastewater enters a grit chamber. Grit consists of sand, road particles, ash and other dense materials. Grit either settles to the bottom of the grit chamber or is pumped or suctioned out through aerated channels. These

channels also contribute to separating oils and greases from the rest of the flow (Forster, 2003). Lastly, primary treatment consists of a sedimentation tank that utilizes gravity to separate settleable solids and particulate organic matter from the wastewater by letting them settle to the bottom of the tank (Forster, 2003).

3.1.1.2 Fixed Film Processes

Fixed film processes are aerobic secondary treatment options in which microorganisms adhere to a fixed surface and degrade organic matter in wastewater as it flows past the biofilm. (Mara & Horan, 2003; Forster, 2003). The microorganisms present include bacteria, protozoa, larvae, worms, fungi, and algae. They develop distinct layers to create a complicated biofilm on the solid surface (Mara & Horan, 2003; Forster, 2003). Figure 7 demonstrates the role of biofilm in sewage treatment. Examples of fixed film processes are trickling filters (which include high-rate biofiltration) and rotating biological contactors.

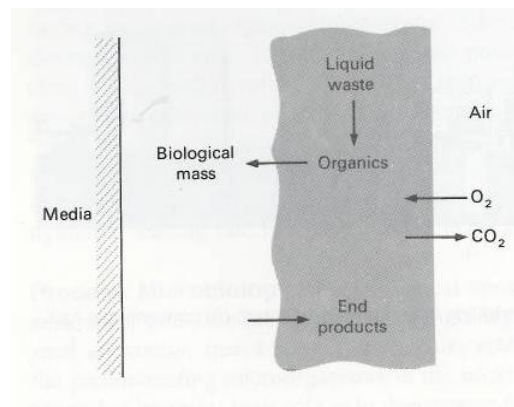


Figure 7. Role of biofilm in fixed film sewage treatment.
(Tchobanoglous & Burton, 1991)

Trickling filters are a fixed film process that uses bed reactors containing media as the solid surface on which the biofilm grows. Stones or plastic may be used as the treatment medium. The structure of the plastic is open with regular geometry, and works in the same manner as stones. The beds generally range from 5 to 10 centimeters in depth (Mara & Horan, 2003). After primary treatment, the wastewater is sprayed through nozzles over the bed reactor. The nozzles are used to distribute the wastewater over the bed and oxygenate the wastewater to

maintain conditions necessary for aerobic digestion (Mara & Horan, 2003). The sewage then moves through the medium, where the attached organisms degrade the organic matter. When the biofilm layer becomes too thick, it is sloughed off. All of the material is transported to a secondary clarifier where the sloughed off biomass settles and is separated as sludge. Figure 8 displays a schematic of a trickling filter. The filters are easy to operate and require minimal levels of maintenance and energy. They are reliable, due to their simple nature, but can become clogged from high levels of biofilm production. Since trickling filters have an open surface, odor problems can develop, which may attract flies (Mara & Horan, 2003). The reactors can be stacked when space is restricted (Bolton & Klein, 1971).

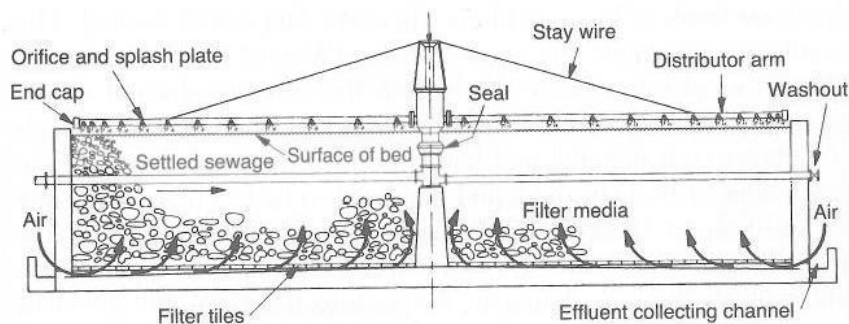


Figure 8. Schematic of a trickling filter. (Forster, 2003)

Rotating biological contactors (RBCs) are another fixed film process in which a series of discs are partially submerged in wastewater. These discs are rotated at a speed of approximately one revolution per minute (Forster, 2003). The biofilm adhering to the discs becomes exposed to the air and wastewater alternately as the discs rotate in order to allow for aerobic degradation of organics in the wastewater. When the developing biofilm becomes thick, it sloughs off of the discs and travels with the water into the secondary clarifier. In the secondary clarifier, the biomass settles at the bottom of the tank to be collected (Mara & Horan, 2003). Figure 9 shows a schematic of a RBC. Biological contactors have low maintenance and energy costs. The sludge produced also settles well in these processes. However, there is a risk of the film drying out when exposed to the ambient air in warm climates (Mara & Horan, 2003).

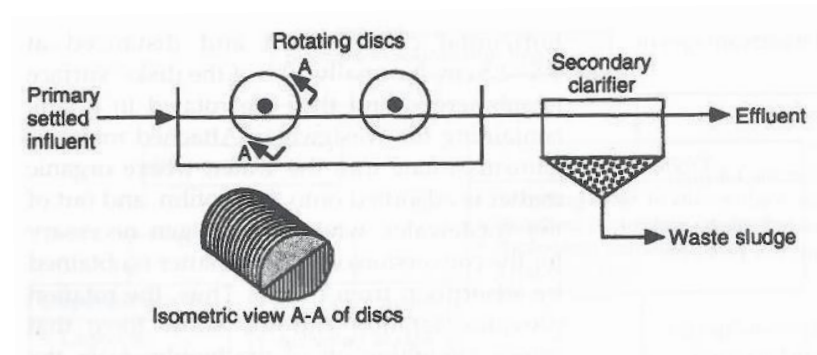


Figure 9. Schematic of rotating biological contactor. (Mara & Horan, 2003)

3.1.1.3 Suspended Growth Processes

In suspended growth processes, a mixture of microorganisms consisting of bacteria, protozoa, fungi, and viruses form a polymeric matrix, called activated sludge (Mara & Horan, 2003; Forster, 2003; Davis & Masten, 2009). This biomass is suspended within the wastewater and degrades soluble organic matter (Mara & Horan, 2003). Wastewater spends an average of 3 to 6 hours in a complete mixed aeration tank, or 6 to 8 hours in a plug flow aeration tank, during which microorganisms degrade organic matter and produce biomass (Dept. of the Army, Navy, and Air Force, 1988). The overflow from the aeration tank enters the secondary clarifier, where effluent is separated from the sludge. A portion of the sludge is transported back into the aeration tank to treat new wastewater and maintain a high concentration of organisms in the aeration tank (Forster, 2003).

The activated sludge process does not require much land (Bolton, Klein, 1971). It also has a low initial cost and produces minimal odors. However, a large amount of sludge is produced as a byproduct and must be disposed properly. The system works more effectively in warm climates, but requires a high level of maintenance (Bolton, Klein, 1971).

3.1.2 Engineered Anaerobic Treatment Systems

Engineered anaerobic treatment systems are the second alternative treatment for centralized treatment systems. Anaerobic digestion is a process to degrade waste without the presence of oxygen. Digestion that occurs anaerobically produces carbon dioxide and methane as

byproducts (Mara & Horan, 2003; Davis & Masten, 2009). Anaerobic digestion is mainly used to process sludge, but it can be used to treat wastewater (Forster, 2003). One option is an upflow anaerobic sludge blanket (UASB). Anaerobic digestion occurs as influent is channeled through the sludge blanket (Forster, 2003). A feature unique to UASB reactors is that gases and solids are separated from each other and from the influent. This allows for the collection of biogas at the top of the reactor, which can be used as a renewable energy source (Forster, 2003). Figure 10 displays a schematic of the process.

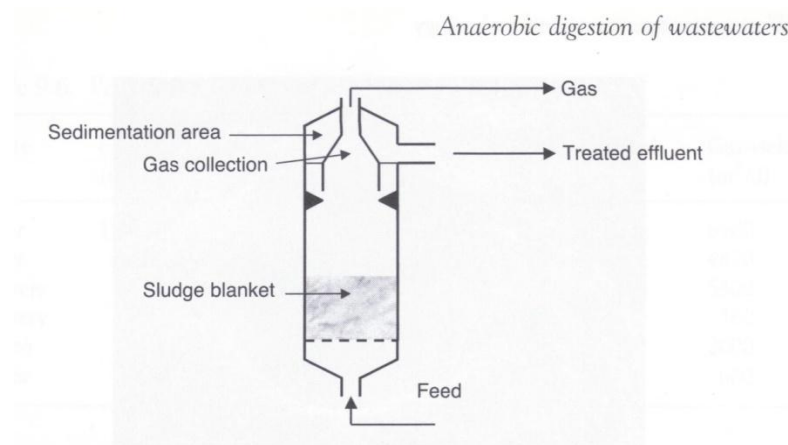


Figure 10. Schematic of anaerobic digestion of wastewater. (Forster, 2003)

The overall cost of anaerobic digestion is inexpensive, but the initial costs are high (Forster, 2003). A small amount of sludge is produced, which limits maintenance. However, the reactors are not capable of removing all excess nutrients from wastewater (Forster, 2003). They do not require a large space requirement, making them a feasible option in urban settings.

3.1.3 Natural Treatment Systems

Natural treatment systems are the final alternative treatment within the centralized treatment options. These systems utilize microbial degradation of organic matter in a natural or constructed setting, such as wetlands or a pond. Natural treatment systems can employ anaerobic degradation, aerobic degradation, or a combination of both, depending on the specific system. Natural systems function well in warm climates and are very efficient in the removal of pathogens in wastewater (Kayombo, 2004). Generally, these systems require low levels of

maintenance and are cost-efficient in terms of capital, operational, and maintenance costs (Kayombo, 2004). However they require a large amount of property, and as a result, natural treatment systems are ideal for small communities with land available for development (Bowker, 1992).

3.1.3.1 Oxidation Ditches

The first examined natural treatment system is oxidation ditches. After pre-treatment, the wastewater flows into an oxidation ditch, where it is held for about a month. Oxidation ditches are aerated by one or more rotors, depending on the ditch size, to promote aerobic digestion. After the necessary residence time, effluent exits the system. In some systems, such as the one showed in Figure 11, a sedimentation tank can be added as a final stage of treatment. The treatment process produces minimal levels of sludge and a high degree of mineralization, which is the conversion of organic matter into inorganic substances (Mara, 1976). There are few odors because of the minimal amount of sludge produced. Oxidation ditches are not as effective as waste stabilization ponds (see section 3.1.3.2) in removing fecal matter, nor are they as cost efficient (Mara, 1976).

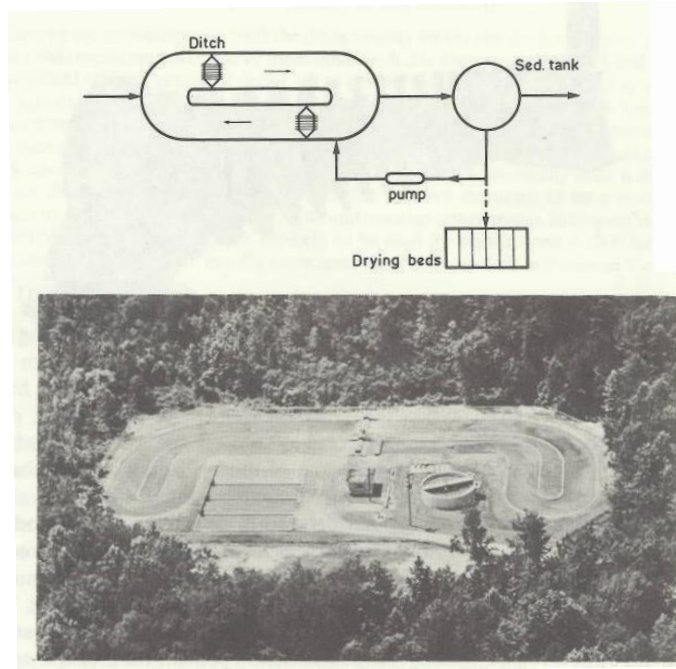


Figure 11. Schematic of an oxidation ditch (top) and sky view of a large system (bottom).
(Mara, 1976)

3.1.3.2 Waste Stabilization Ponds

Waste stabilization ponds are large, shallow basins enclosed by earthen banks. They are typically designed as a series of three ponds, with an anaerobic, a facultative, and a maturation pond (Bowker, 1992; Kayombo, 2004). The anaerobic and facultative ponds reduce the concentration of organic matter, while maturation ponds are effective for reducing pathogen concentrations (Kayombo, 2004). Raw sewage is first deposited into the anaerobic pond where digestion begins. In the facultative and maturation ponds, photosynthetic activity from algae produces oxygen which allows for aerobic digestion. In general, waste stabilization ponds require little maintenance and are inexpensive to sustain (Kayombo, 2004). Hotter climates act as a catalyst to the degradation of waste (Mara, 1976). While these ponds are economically plausible, land constraints can pose a significant barrier to their use.

3.1.3.3 Constructed Wetlands

Constructed wetlands are systems that use plant roots to degrade waste. Water flows horizontally or vertically through the saturated ground or substrate that holds the plants (Bowker, 1992). The plants enable oxygen transportation to the roots, where bacteria gather to aerobically digest waste in the influent (Mara, Horan, 2003). Reed beds can be either free-water surface systems, which have water exposed to the air, or subsurface flow systems, where the water flows through substrate underground (Bowker, 1992). Constructed wetlands must be preceded by some form of treatments and are therefore commonly used as secondary or tertiary treatments (Forster, 2003; Kayombo, 2004).

3.1.4 Composting Toilets

Composting toilets are a decentralized alternative treatment that treats black water. Composting toilets do not require water in order to degrade waste. They aerobically digest excrement, toilet paper, and some food wastes (Gehring, 2011). When the containing chamber within the toilet fills, the resulting compound, called humus, is removed to be used as a fertilizer or is buried (Gehring, 2011). Challenges have been encountered when designing a composting toilet that eliminates human contact with composting material while still allowing it to be exposed to air (Gehring, 2011). In general, composting toilets are most effective for the elimination of pathogens in waste (McClellan, 2009).

Urine diverting toilets can also be implemented within single households or can be shared by the residents of a small group of households. These are a particular type of composting toilets that consist of two containment chambers: one for fecal matter and another for urine. The urine is collected separately through the front of the toilet's squat plate and is diverted into a separate tank (Morgan, 2007). Solids are then collected separately, which decreases the amount of water present and thus creates a faster composting process. When the solids container fills, the contents can be easily transported, due to the lack of water, to a separate composting site. The urine collected can be converted into liquid fertilizer to be used in agriculture (Morgan, 2007).

3.1.5 Septic Systems

Septic systems are the final alternative treatment for decentralized treatment of wastewater. Septic systems are typically used for treatment of wastewater from one home or multiple homes. Black and grey water are piped from drains in the house into a common pipe that leads to the septic tank. Septic holding tanks are rectangular chambers that retain sewage. They are typically located underground, but can be used above ground as well. Solids settle to the bottom of the tank, where they undergo anaerobic digestion. The layer of sludge that accumulates at the bottom of the tank is removed through pumping every one to five years, depending on the amount of use and the size of the tank (Mara, 1976).

The effluent from the septic holding tank flows into the leach field. As effluent flows through the leach field, the nutrient-filled soil type absorbs the treated water. There are two different types of leach fields: leach beds and leach pits. Leach beds require perforated pipes that distribute the treated water over a field of a specific type of soil. Leach pits are vertical pits usually ranging from 10 to 40 feet in depth (Kaplan, 1991). Both types allow for soil absorption. While leach fields are typically used after septic tanks, other treatments can be used to treat the effluent from the septic tank.

3.1.6 Redirection

Redirection of wastewater is not a direct treatment system, but it accomplishes the immediate task of eliminating discharge of untreated wastewater into a natural environment. This helps to reduce the contamination of local surface waters and ground waters that could be used for municipal, recreational, or drinking purposes. Redirection has options that include channeling wastewater into a containment tank or connecting households to an existing sewer. A containment tank would hold the wastewater until it could be emptied and transported to another location for treatment and/or disposal. A centralized containment tank would have to be emptied on a regular basis. Connection to an existing sewer line would take the wastewater to a large scale centralized treatment system. This is a passive system that would require minimal upkeep besides repairing leaks or clogs (Rijn, 2006).

3.1.7 Conclusion

Six classes of alternative wastewater management were described above: engineered aerobic treatment, engineered anaerobic treatment, natural systems, composting toilets, septic tanks, and redirection. Using information on the advantages and disadvantages of each system, we evaluated the options for managing wastewater in Fátima, as described in the following sections.

3.2 Methods of Study 2

The goal of this study was to provide the homes in Fátima that border the Quebrada Padre with an improved option for wastewater management. We used our research on wastewater management options to select a feasible option based on criteria such as maintenance, cost, and constructability.

3.2.1 Wastewater Management Systems Analysis

First, we researched wastewater treatment and/or disposal options as described in section 3.1. This was accomplished by consulting environmental engineering reference books and articles specific to wastewater management. After conducting research, we evaluated each option based on the following criteria: maintenance, cost, constructability, durability, safety, and efficiency. Maintenance was based on the expected frequency of repairs for the system. Costs were based on what was needed for construction, operation, and maintenance of the system. Constructability was based on ease of implementation with the current infrastructure, land requirements, and material availability. Durability was based on the lifespan of the system. Safety was based on the potential for exposure to pollutants. Efficiency was based the reduction of contaminants through treatment.

Each of the criteria was given a weighing factor using a pair-wise comparison chart. In this method, criterion are compared in pairs and scored 0 (less important), 0.5 (equally important), or 1 (more important) when compared to each other. The scores were totaled and compared to show the relative importance of each criterion. Each criterion score was then

divided by the sum of the scores and converted to a percentage. The percentages were adjusted qualitatively to create finalized weighing factors that most accurately matched the needs outlined by the Association. This was done according to Salustri's process of analyzing pair-wise comparison charts (2005).

Once the weighing factors were determined, each treatment and/or disposal option was ranked for each criterion on a scale from 1 to 10; 1 being not feasible and 10 being very feasible. The scores for each criterion were multiplied by their respective weighing factors and summed to produce a final score from 0 to 100. The wastewater management option with the highest final score was selected as the most viable option for Fátima. We also recommended a secondary wastewater treatment as an alternative to our primary recommendation in case the Association is unable to implement the primary.

3.3 Results of Study 2: Wastewater Management Recommendation

The homes on the Quebrada Padre discharge untreated wastewater to the river, causing the water quality to degrade. Therefore, alternative systems for wastewater management were investigated. Wastewater management systems were evaluated on the following criteria: maintenance, cost, constructability, durability, safety, and efficiency. The pair-wise comparison values, total pair-wise scores, and weighing factors that were assigned for each criterion are shown in Table 2. Detailed calculations for conversion from pair-wise scores to adjusted weighing factors are shown in Appendix B.

Table 2. Pair-wise comparison chart to determine weighing factors.

Criteria	Pair-wise Comparison of Criteria						Pair-wise Total Score	Adjusted Weighing Factor
	Maintenance	Cost	Constructability	Durability	Safety	Efficiency		
Maintenance	x	1	1	1	1	1	5	30
Cost	0	x	1	1	1	1	4	25
Constructability	0	0	x	1	1	1	3	13
Durability	0	0	0	x	1	1	2	20
Safety	0	0	0	0	x	0.5	0.5	6
Efficiency	0	0	0	0	0.5	x	0.5	6
TOTAL							15	100

The two highest weightings were given to maintenance and cost because it was determined in Study 1 that money and required maintenance were the main barriers to the success of a wastewater management system for Fátima. Constructability ranks third, which entails the short term success, in terms of feasibility of implementation and construction of the system. Next is durability, which entails the long term success, in terms of the lifespan of the system. The two criteria holding the least weight were safety and efficiency. The current piping system with no treatment lacks safety based on human health risks. Also, the current piping system lacks performance as there is no treatment of the waste. As such, implementation of an alternative would improve upon the current system. Since all treatment options would enhance these criteria, they were not weighted as heavily as other factors.

The wastewater management system selection process was completed in three phases: (1) septic holding tank scale evaluation; (2) septic tank post-treatment evaluation; and (3) system evaluation. The first two phases were used to compare portions of systems to narrow down the options. The third phase incorporated the preferred options from phase 1 and 2 plus additional options for complete wastewater management systems.

In the first phase, septic holding tanks were compared for use as individual (decentralized) tanks or community (centralized) tanks. Table 3 shows a comparison of these two options. Centralized and decentralized septic tanks were ranked similarly on all criteria except cost and constructability. The cost to install one tank for each house would be much higher than the cost needed to install a single community tank. Constructability is also low for individual tanks because there is not sufficient space between the houses and the river for installation. Based on the higher constructability and cost scores, centralized septic holding tanks were selected for further study.

Table 3. Analysis matrix for comparison of centralized vs. decentralized septic holding tanks.

Criteria		Maintenance	Cost	Constructability	Durability	Safety	Efficiency	Total
Weighing Factor		30	25	13	20	6	6	100
Process								
Centralized septic tank	ranking 1-10	7	8	7	8	9	7	
	weighted ranking	21	20	9	16	5	4	76
Decentralized septic tank	ranking 1-10	8	5	4	8	9	6	
	weighted ranking	24	13	5	16	5	4	67

Septic holding tanks are the first portion of a wastewater treatment system. After waste is collected into a common tank, the waste is held for a certain time while the suspended solids settle out and biodegradation with microorganism begins. Then, the overflow from the tank passes to an additional treatment process that helps to further degrade the organic matter and nutrients to make the effluent meet discharge standards. Therefore, phase 2 of the wastewater management system selection process examined four options to be combined with septic holding tanks. Constructed wetlands, trickling filters, rotating biological contactors, and leach fields were considered. Constructed wetlands received the highest ranking of the four options. Constructed wetlands, being a natural system, has a significantly lower capital cost than the other engineered options, and therefore received a score of 7 over a 4 and 5 for RBCs and trickling filters, respectively. Leach fields, which generally act as the secondary process of a septic system, received low scores in constructability, safety, and efficiency because impermeable clay soil in Fátima prevents adequate treatment. Based on the results of these comparisons, centralized septic holding tanks were combined with constructed wetlands to create a complete system that could be considered as an option for Fátima. Table 4 shows this ranking process.

In phase 3, complete systems for wastewater management were compared. The eight systems included centralized and decentralized options, engineered and natural options, and an option that redirects the water to a municipal sewer system (see Table 5). The list of complete systems was determined through past research. The following paragraphs are organized by each criterion in the analysis matrix. Every paragraph begins with a discussion of the system receiving the highest ranking in that criterion and ends with the discussion of the system receiving the lowest ranking.

Table 4. Analysis matrix for comparison of secondary treatments to be combined with a septic tank

Criteria		Maintenance	Cost	Constructability	Durability	Safety	Efficiency	Total
Weighing Factor		30	25	13	20	6	6	100
Process								
Constructed wetland	ranking 1-10	7	7	8	8	7	6	
	weighted ranking	21	18	10	16	4	4	73
Trickling filter	ranking 1-10	6	5	7	8	7	6	
	weighted ranking	18	13	9	16	4	4	63
Rotating biological contactors	ranking 1-10	6	4	6	7	8	6	
	weighted ranking	18	10	8	14	5	4	58
Leach field	ranking 1-10	7	7	1	6	3	3	
	weighted ranking	21	18	1	12	2	2	55

Table 5. Analysis matrix for comparison of complete systems

		Criteria	Maintenance	Cost	Constructability	Durability	Safety	Efficiency	Total
		Weighing Factor	30	25	13	20	6	6	100
		Process							
Cent.	Eng.	Engineered activated sludge	ranking 1-10	6	4	6	8	8	
			weighted ranking	18	10	8	16	5	61
		Trickling filter	ranking 1-10	6	5	6	8	7	8
			weighted ranking	18	13	8	16	4	5
		Rotating biological contactors	ranking 1-10	6	4	6	7	8	
			weighted ranking	18	10	8	14	5	59
		Anaerobic digestion	ranking 1-10	6	5	6	7	7	8
			weighted ranking	18	13	8	14	4	5
	Nat.	Waste stabilization pond	ranking 1-10	8	7	4	8	6	8
			weighted ranking	24	18	5	16	4	5
Decent.	Eng.	Composting toilets	ranking 1-10	4	8	6	6	8	8
			weighted ranking	12	20	8	12	5	5
	Eng.	Connection to existing sewer	ranking 1-10	8	9	8	6	9	4
			weighted ranking	24	23	10	12	5	2
	Comb,	Centralized septic tank + constructed wetland	ranking 1-10	7	7	7	8	7	9
			weighted ranking	21	18	9	16	4	5
Redir.	Eng.	Connection to existing sewer	ranking 1-10	8	9	8	6	9	4
			weighted ranking	24	23	10	12	5	2

Key: Decent.= Decentralized, Cent.= Centralized, Redir.= Redirection, Eng.= Engineered, Nat.= Natural, Comb.= Combined

As shown in Table 5, each system was ranked 1 to 10 for each of the criteria. Maintenance was ranked based on hours required yearly to maintain the system, possible repairs, and specialists needed for maintenance. The cost associated with maintenance was considered in the cost category. Connection to the sewer received a score of 8 in maintenance. For this option, repairs include leaking pipes or clogged pumps. The pipe network would need to be cleaned once every two months and flushed at least once a year (Rijn, 2006). Natural systems also received high scores (7 – 8) because they are passive systems requiring minimal operation skills and therefore fewer specialists (Bowker, 1992). The only maintenance required is weekly monitoring for flow requirements and repairs to the overall structure of constructed wetlands (Bowker, 1992). Centralized treatment systems such as RBCs, activated sludge, trickling filters, and anaerobic digestion received rankings in the medium range. These systems require daily monitoring by professionals and all systems have moving parts that can fail (Wik, 2003; Cortez, 2008; Richwine, 1984; Patwardhan, 2003). Composting toilets received a rank of 4 for maintenance because these require weekly upkeep by the residents and yearly emptying (McClellan, 2009; Crennan, 2007).

The cost ranking was based on a combination of initial capital cost and operational and maintenance costs. Connection to the sewer received a score of 9 for cost because it has the lowest start-up and maintenance expenses. The grinder and pump each cost approximately 1000 US dollars (500,000 colónes) (Rijn, 2006). Composting toilets received a score of 8 for cost because each toilet could be constructed for between 1,000 and 10,000 US dollars (500,000 and 5,000,000 colónes), depending on the design (McClellan, 2007). The natural systems received rankings in the medium range because they do not have high startup costs that come with engineered systems (Bowker, 1992). The engineered systems were all scored 4 or 5. Activated sludge has high energy requirements and maintenance costs (Bowker, 1992). RBCs, trickling filters, and anaerobic digesters have capital costs of over 100,000 US dollars (50,000,000 colónes) (Bowker, 1992; Dept. of the Army, Navy, and Air Force, 1988).

Constructability was rated based on size, location constraints, and material availability. Connecting to the sewer received a ranking of 8. Construction is simpler relative to the other systems because an above-ground pipeline does not require extensive excavation or mechanical construction. Based on measurement estimations from a scaled map, approximately 500 meters of pipe would be needed to connect the existing wastewater disposal pipes to the sewer system.

Septic tanks and constructed wetlands received a score of 7. Natural systems involve a higher level of excavation and a lower level of mechanical assembly than engineered systems, but take up more land (Bowker, 1992). However, the land is still useable because the septic holding tank is located underground and the constructed wetlands are visually appealing. Wetlands increase the biodiversity of the area with plants and wildlife habitats (Bowker, 1992; Kayombo, 2004). The remaining engineered systems all received a score of 6. The size of each centralized engineered plant would be a relatively small based on the low flow rate from the 30 houses, but these systems are not easily constructible due to the large number of mechanical parts (Davis & Masten, 2009; Patwardhan, 2003; Cortez, 2008). The media for a tricking filter can be plastic, stone, or wood and can therefore be selected from a local supplier (Cortez, 2008). Composting toilets received a 6 because they would replace the existing toilets and require installation of a waste containment pit below the house (Crennan, 2007). Finally, waste stabilization ponds received a score of 4 because they take up a significant amount of space. A minimum of three ponds would be needed to complete the treatment process (Bowker, 1992). This natural system also leaves the land it occupies unusable for other purposes.

Durability was ranked based on the lifespan of the system. The centralized engineered systems and centralized natural systems received scores of 7 or 8 for life expectancy. Each has an approximate lifespan of 10-20 years (Shutes, 2001; Cortez, 2008; Bowker, 1992; Dept. of the Army, Navy, and Air Force, 1988). Connection to the sewer and composting toilets have a lower life expectancy of approximately 10-12 years and therefore received a score of 6 (Rajin, 2006; Crennan, 2007).

Safety was ranked based on human health risks from exposure to pollutants. All of the systems were ranked from 6 to 9. Composting toilets and connection to the sewer received the highest rankings. In both cases, there is little to no risk of human exposure to wastewater. By connecting the wastewater to the existing sewer system, the wastewater is rarely exposed to the open air, presuming that there are no leaks in the pipes. In composting toilets, all liquids are eliminated and only solid waste byproduct is removed from the system (Crennan, 2007). The options that received the mid-level scores were the engineered systems because treatment plant workers would be exposed to wastewater (Bowker, 1992; Patwardhan, 2003; Forster, 2003). The options that received the lowest scores were the natural systems, since they leave the wastewater open to the air, thus enabling a higher risk of human contact (Bowker, 1992).

Efficiency was based on the level of pollutants present in effluent that would be discharged into the natural environment. The pollutants researched included biochemical oxygen demand (BOD), suspended solids (SS), nitrogen, phosphorus, and pathogens. Composting toilets received a ranking of 9. Composting toilets do not introduce effluent water into the natural environment and are excellent at reducing pathogens (Crennan, 2007). Natural systems and engineered treatment plants all received a score of 8. Natural systems have high residence times, but the process can efficiently reduce pathogens, organic matter, and nutrients. Also, pathogen removal would be particularly efficient in Fátima because the process is more efficient in tropical climates (Bowker, 1992; Kayombo; 2004). Engineered systems have high BOD and SS reduction and include multiple stages of treatment within the system (Patwardhan, 2003; Wik, 2003; Forster, 2003). Connection to the sewer received the lowest performance rating of a 4 because wastewater connected to the sewer is currently not treated properly (AyA, personal communication, Nov, 14, 2011). AyA currently has a project in progress to develop a treatment plant for this larger issue (Unidad Ejecutora AyA, 2011). Implementation of this treatment plant would increase the performance rating of this disposal system.

As shown in Table 5, the individual criterion scores were multiplied by their weighing factors, and the weighted scores were summed to produce a total weighted score. The scores for the wastewater management options ranged from a low of 59 for rotating biological contactors to a high of 77 for connection to existing sewer. The highest ranking system that involves direct treatment was a septic holding tank combined with a constructed wetland which received a total score of 73. However, connection to the public sewer received the highest scores compared to all other systems in the top three criteria: maintenance, cost, and constructability. The total score shows that this disposal system is the most viable wastewater treatment and/or disposal option for the residents that border the Quebrada Padre.

Based on these findings, we recommend that the Association connect the existing household pipes that empty into the river to an existing sewer line. This system requires approximately 500 meters of pipe to be laid above ground and follow the path of the river downstream and reconnect to the sewer north of Fátima at the edge of the neighboring barrio of San Lorenzo. We recommend that a topographical analysis be conducted to confirm the best path for the pipe that will require the least amount of outside energy. All necessary energy to transport wastewater to the connection site, which is at a higher elevation, can be provided with a pump.

Before entering the pump, the sewage may need to go through a grinder to minimize clogging. This method will accomplish the goal of cleaning the Quebrada Padre since it will eliminate wastewater from Fátima from entering the river.

3.4 Discussion of Study 2

In Study 2, we evaluated wastewater treatment and/or disposal options, and recommended that the homes be connected to the existing municipal sewer. This system has low capital costs, low maintenance, and does not require significant space for construction. The current infrastructure, including the pipes that extend from the houses and the existing sewer system, can be utilized as part of the new system. Lastly, connections to the sewer would eliminate the discharge of untreated wastewater from these homes into the Quebrada Padre.

Our primary recommendation removes wastewater from Fátima but does not involve direct treatment. If the Association is unable to implement our primary recommendation, we recommend a centralized septic holding tank accompanied by a constructed wetland as a second option. This system has relatively low capital and maintenance costs. Additionally, the use of an underground septic holding tank for pre-treatment decreases the land requirement often needed for a natural system, which allows the community members more land for recreation. However, our primary recommendation is easier to construct, maintain and finance.

The recommended option of connection to a sewer requires an initial capital cost and operation and maintenance costs. The capital costs include purchasing of materials including piping and a pump as well as the cost of labor for installation. The operation and maintenance costs include electricity to run the pump and maintenance costs for repairing leaks and clogs. The Association, which is responsible for the development of the town's infrastructure, does not currently have the funds to implement this recommendation (The Association, personal communication, Oct. 29, 2011). Therefore, financing options for the project should be explored.

Chapter 4 – Conclusions and Future Recommendations

In the community of Fátima in Desamparados, Costa Rica, the residents currently discard untreated wastewater in the Quebrada Padre, causing the water quality to degrade. The goal of this project was to assess the residents' perceptions on their wastewater disposal system and recommend the most feasible wastewater management system. Two studies were conducted to accomplish this goal. The first study showed that many of the residents were unaware of their current wastewater disposal system and the current state of the Quebrada Padre. From Study 1, we concluded that there was a need to identify improved wastewater management strategies. In our second study, we examined potential management options. Based on this research, we recommend that the community connect the existing pipes to the municipal sewer system. In comparison to others, this solution will be the most cost effective, easiest to maintain and easiest to implement.

Financing Options. To ensure financial feasibility for implementation of the project, we recommend that the Association explore the following financing options: (1) encouraging the residents to financially contribute, (2) fundraising, and (3) exploring financial aid from external sources. Residents may be more willing to contribute a portion of the cost if they found the cause to be worthy and essential to their personal needs (Barr, 2011). To encourage this, we obtained information on how wastewater management may relate to the personal needs of the residents of Fátima. First, the Association indicated that the property values of the homes that border the Quebrada Padre would increase through quality improvement of the river and implementation of a new management system (The Association, personal communication, Nov. 30, 2011). Second, the Association stated that the risk for back-up and flooding of wastewater in pipes is reduced through implementation of a new system (The Association, personal communication, Nov. 30, 2011). Dedicating money to implement the system can be seen as an investment in the residents' property.

The second option is fundraising. This aligns with the goals of the Association to not only improve the infrastructure of the neighborhood, but also improve the social well-being of the community. In the past, the Association has held fundraising events to raise money for the needs of the town (The Association, personal communication, Oct. 29, 2011). Successful fundraising

events in the past have included hosting carnivals, fairs, and bake sales. Other potentially successful ideas to raise funds include raffles or organized sporting competitions. These activities can be executed with minimum financial budget provided by the Association to yield profits.

The final option for financing involves acquiring grants from external sources. In Costa Rica, many organizations offer grants because of their commitment to improve the quality of the environment. Some of the companies that can be considered include the Rufford Small Grants Foundation (RSGF), Intel, and Terra Viva Grants. Given the three different options for financing the project costs, future research should investigate which of these financing options would be the most suitable for use in the community of Fátima based on the available resources of the Association.

Attitudinal and Behavioral Change. To maximize the potential for long term success in managing wastewater in Fátima, we recommend additional study on resident attitudes and behaviors. While we assessed attitudes and behaviors regarding wastewater disposal and the river, we did not explore ways to change attitudes and behaviors. Future research on this topic may encourage the long term success of keeping the Quebrada Padre free from anthropogenic pollution. Past research suggests two mechanisms to change attitudes and behaviors: direct (targeting cognitions) and indirect (using peripheral cues).

More specifically, an example of a direct approach to changing attitudes and behaviors is through the use of educational programs (Quimby & Angelique, 2011; Barr, 2007). The objectives of a community education program are to inform people of the problem that they are facing and to provide them mechanisms to address (or fix) the problems (DeYoung, 1993). According to research by DeYoung (1993), this can be done in one of two ways: 1) providing factual information about environmental concerns and ways to change, or 2) through active learning or direct experience with the issue at hand. Both can effectively lead to changes in behaviors, though sometimes direct experience can have longer lasting effects because individuals gain a more personal understanding of the problem (DeYoung, 1993).

In contrast, the indirect approach has a subtler and often more unconscious effect on attitudes and behaviors. One way that the indirect approach could be implemented is through mere exposure to a stimulus. The more frequently individuals are exposed to a stimulus then the

more likely they are to experience positive feelings for it (Zajonc, 2001). The execution of this could be done with environmentally friendly messages to expose residents to the idea of sustainability. A second way that the indirect approach can be implemented is by creating a “green default”—or an environmentally friendly option that is essentially the only option. For instance, one found that when an environmentally friendly electricity source was the default source of electricity, then individuals were more likely to use this type of energy (Pirchert et al., 2007). In addition, research shows that the effectiveness of defaults at affecting behavior increases when the user is not familiar enough with the subject and therefore prefers to not make a decision (Pirchert, et al., 2007). Thus, given the two different approaches that can influence residents’ attitudes and behaviors, future research should investigate which of these mechanisms would be more effective in encouraging residents to be more environmentally conscious with their wastewater disposal practices.

Conclusion. We recommend connecting the homes to the municipal sewer system to reduce the amount of untreated wastewater that is discharge into the Quebrada Padre. Based on the research we conducted regarding the perceptions of the residents towards the environment, future work should be conducted to help ensure the success of our recommendations. We recommend that the Association research funding options to implement sewer connections in the hope that the new wastewater system will promote pro-environmental behaviors. Since residents in the community are not fully aware of or concerned with environmental problems, future research should be directed towards affecting their attitudes on the matter. By connecting homes to the municipal sewer, the water quality in the Quebrada Padre and the environmental conditions in the community of Fátima can be improved.

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Appendix A – Fátima Resident Interview Questions

- 1) Does it seem to you that the Quebrada Padre is slightly, moderately, or highly contaminated?

¿Le parece a usted que la Quebrada Padre está poco, medianamente o muy contaminada?

- 2) What discomforts does the pollution of the Quebrada Padre cause you?

¿Qué molestias le causa la contaminación de la Quebrada Padre?

- 3) What causes the contamination of the Quebrada Padre?

¿A qué se debe la contaminación de la quebrada Padre?

- 4) Where does the black and grey water of this house go?

¿A dónde van las aguas negras y agua de pila de esta casa?

Appendix B - Pair-wise Comparison to Determine Decision Matrix Weighing Factors

Weighing Factor Calculations:

$$\frac{\text{total}}{\Sigma \text{totals}} * 100 = \text{weighing factor}$$

$$\text{Constructability: } \frac{3}{15} * 100 = 20$$

$$\text{Safety: } \frac{.5}{15} * 100 = 3.33 \cong 3$$

$$\text{Cost: } \frac{4}{15} * 100 = 26.66 \cong 27$$

$$\text{Durability: } \frac{2}{15} * 100 = 13.33 \cong 13$$

$$\text{Maintenance: } \frac{5}{15} * 100 = 33.33 \cong 33$$

$$\text{Efficiency: } \frac{.5}{15} * 100 = 3.33 \cong 3$$

Based on the process outlined by Salustri (2005), the calculated percentages were adjusted to produce weighing factors that were satisfactory to all stakeholders. The main adjustment was made so the range between the factors was reduced. The final values used for analysis are listed in the table below.

Table 6. Adjusted weighing factors to be used in analysis

Criteria	Maintenance	Cost	Constructability	Durability	Safety	Performance
Weighing Factor	30	25	13	20	6	6